

AD A 096483

LEVEL

(11)

Yw

(9) *Research and development*
ED Status Report -
For Period
5 June 1978 - 5 September 1980,

(6) **ADVANCED ALUMINUM ALLOYS**
FROM
RAPIDLY SOLIDIFIED POWDERS.

(14) **LMSC-D777825** ✓

(11) **September 1980**

A087 401

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(415 - 493-4411, Extension 45743)

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Sponsored by
Defense Advanced Research Projects Agency (DoD)
DARPA Order No. 3417

Monitored by
Air Force Materials Laboratory
Air Force Systems Command
United States Air Force
Wright-Patterson AFB, Ohio 45433

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(15) **Contract No. F33615-78-C-5203**
Effective 5 September 1978 to 5 June 1982

DARPA Order - A 3417

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process development and optimization. The most promising alloys are to be selected, produced in simple mill form, and evaluated in Phase 2. Phase 3 will consist of a design evaluation using the properties of the alloys evaluated in Phase 2.

This program was initiated in September 1978 and is scheduled for completion in 3-1/2 years. The effort during the first two years will be devoted to Phase 1 only. This report describes activity during the reporting period in each of the four tasks comprising Phase 1.

3.0 PROGRESS

3.1 Task 1 - Development of Alloys Containing Lithium

This task is being performed by LMSC with Dr. I. G. Palmer as principal investigator.

Characterization of Heat Treated Alloys

Oxygen Analysis of Consolidated First Iteration Alloys. Fast Neutron Activation (FNA) oxygen analyses have been performed by IRT Corp. on extruded material of all first iteration alloys. The results are given in Table 1, together with relevant extrusion data where they are also compared with the loose flake oxygen analyses performed previously (Ref. 1). No significant correlation was observed either with the loose flake oxygen analyses, or with parameters such as storage time prior to consolidation or observed amount of degassing during the vacuum hot pressing operation.

Second Iteration Alloys: Splat

Particulate Preparation and Characterization. Argon atomized splat particulate was obtained from Alcoa for the four second iteration Al-Li based alloys. Table 2 summarizes applicable production information. Duplicate runs of alloy 1.11 were required due to the inadvertent loss of the argon atomizing gas supply early during the first splat-making attempt. Rather than simply scrap the remaining melt, splat-making was resumed using air atomization and the resultant flake product was retained for comparison with the argon atomized flakes produced in a subsequent run.

Use of larger, lithium-resistant crucibles enabled Alcoa to omit one melt holding and molten metal transfer step from the prior practice. Alloys were prepared exactly as for first iteration splat alloys prepared previously, with the exception that initial melting, fluxing and lithium additions were all accomplished in the same crucible. Larger, 31.82 kg (70 lb) starting melt weights were employed in an attempt to increase the net yield of good splat flakes. However, skim losses in these Al-Li-Mg alloys significantly exceeded those experienced in the prior Al-Li compositions and resulted in low melt recoveries as noted in Table 2.

Screen fraction analyses of the five splat runs are given in Table 3, and chemical composition analyses, by atomic absorption, in Table 4. Sodium contents of the melt samples were determined, but potassium contents were not, since prior Alcoa analyses failed to detect measurable trace quantities.

Consolidation and Characterization . Consolidations have been made using both as-received unscreened particulate and particulate having the +8 and - 50 screen fractions removed. Preliminary tensile data have been obtained for the same aging treatment [463K (375°F) for 8 hr.] as used for the peak aged condition of the first iteration Al-Cu-Li alloys. Aging curves are currently being determined, and the results so far show that the hardness peak is displaced to longer aging times for these Al-Li-Cu-Mg alloys than for the first iteration Al-Li-Cu alloys. This means that the preliminary tensile data, which is shown in Table 5, represent a slightly underaged condition.

It can be seen that the alloys made from screened particulate show, in general, higher ductility than those made from unscreened particulate, in accordance with previous findings. All future consolidations will therefore be made using screened particulate.

Alloys 1.9 and 1.10. These alloys show rather low yield strength values. It is thought that this is a result of two factors, firstly the slightly underaged condition, and secondly the fact that the alloys are in a recrystallized

condition. Metallographic examination shows an inhomogeneous recrystallized grain structure which is more pronounced in alloy 1.9 than in alloy 1.10. The recrystallization and grain growth presumably occurred during the solution treatment [811K(1000°F) for 30 min.]. The alloys also show very different stress strain curves. Alloy 1.9 shows a significant amount of serrated yielding, whereas alloy 1.10 shows very little. The significant differences in both grain size and deformation behavior make a comparison of the alloys difficult at the present time. Short time solution treatments in a lead bath will be used in an attempt to produce finer and more uniform grain sizes in future work on these alloys.

Alloys 1.11 and 1.12. The stress strain curves of these alloys are smooth and show no serrated yielding. Both alloys show reasonably high strengths and very good ductility. Alloy 1.12 shows the highest yield strength and also a slightly higher ductility than alloy 1.11. The higher yield strength is attributed to the presence of Zr, and is probably the result of a finer sub-grain size, stabilized by the Zr.

The elastic modulus and density have not yet been measured for alloy 1.12. The lithium level (1.6 wt %) is slightly lower than the target value of 2.0 wt%, which will result in a specific modulus value slightly lower than for program goal B. However in the strained and aged condition (See Section 3.3) the alloy shows excellent tensile properties (yield strength 546 MPa (79.2 KSi) and elongation 11.4%) and it is clear that even in its present form the alloy is capable of meeting or exceeding property goal B specific strength and ductility values.

Second Iteration Alloys: Fine Atomized Powders.

LMSC has agreed to Alcoa's request to have LMSC's atomized powder items supplied by Valimet, an established aluminum alloy powder producer whose He-inerted system is more compatible to the manufacture of these Al-Li compositions than is Alcoa's atomizing system. All arrangements will be handled by Alcoa. A purchase order was submitted August 1, 1980, with delivery promised by 6-8 weeks after receipt of order. Alcoa has also shipped to

Valimet 91 kg of 99.99% purity aluminum base metal, 2 kg of high-purity lithium and 1.6kg of Al-6% Zr master alloy for use in production of two 45 kg atomized powder lots.

Additional lots of fine atomized powder will be obtained by LMSC from Pratt and Whitney Aircraft Corporation, W. Palm Beach, Florida, using remelt stock supplied by LMSC. Ingots of one alloy have already been supplied to Pratt and Whitney, and ingots of other alloy modifications will be supplied by the end of September.

3.2 Task 2 - Development of Non-Lithium-Containing Alloys

This task is being conducted by the Alcoa Laboratories, with Dr. H. G. Paris and Mr. F. R. Billman as principal investigators.

On the basis of mechanical property evaluation of the first iteration alloys, Tables 6 and 7, it has been found that contract goal A is accessible in an Al-6 atomic percent Mn alloy. It appears that a specific modulus intermediate to goal A and goal B is accessible in the Al-Fe-Ni-Co system. Higher Co:Ni ratios produce higher modulus of elasticity while lower ratios produce higher strength levels. The Al-Mn-Si alloy offers the potential of higher strength and ductility at higher solute contents. This also may offer improved secondary properties, such as elevated temperature strength. The mechanical properties of the better first iteration alloys are given in Table 7. The data in Table 7 show that maintaining a high strength level by minimizing microstructural coarsening in metal processing is the primary challenge for metallurgical design.

The results of the first iteration of alloys suggest a further lowering of the hot pressing and extrusion temperature from 675 K (755°F) to 615-645K (650-700°F) may produce substantially higher strength. The major limitation to the use of lower processing temperatures is the high flow stress of the alloy which can prohibit breakout in extrusion or cause cracking in forging due to limited hot ductility.

These results also show that fine atomized powder obtains cooling rates comparable to splat quenching. Since process studies to improve the solidification rate of the splat-making process are specifically not a part of this program, fine atomized powder is the primary particulate for the second iteration of alloy compositions.

Second Iteration Alloy Selections

On the basis of the previous considerations, the alloys in Table 8 are proposed for the second iteration of compositions. Compositions are selected to meet goal A or to produce high levels of strength and ductility at a specific modulus intermediate to goal A and goal B.

Generation of Particulate. About 45kg (100 lb) each of the four nominal compositions in Table 8 have been atomized, producing powder with the indicated size characteristics. Guinier analysis of the -100 mesh product indicates the presence of some second phases (Table 9). Two of these compositions, alloys 2.10A and 2.11A, will be produced in splat particulate. The schedule for splatmaking is not well established at this time.

Consolidation The alloys will be consolidated and extruded or forged at the temperatures noted in Table 10. Process 1 was used in the first iteration and serves as a process control in the second iteration, while processes 2 and 3 are selected for potentially higher strengths. Consolidation is currently underway with all cold compaction being completed.

3.3 Task 3 - Quantitative Microstructural Analysis and Mechanical Property Correlations

This task is being conducted by Georgia Institute of Technology with Dr. E. A. Starke, Jr. as principal investigator.

FIRST ITERATION Al-Li-X ALLOYS SUPPLIED BY LMSC

The crystallographic textures have been determined for extrusions of alloy 1.2 (Al-3Li-2Cu-0.2Zr) with different cross section aspect ratios (width/thickness). Previously conducted tensile tests at LMSC resulted in significantly different yield strength values for these extrusions, ranging from 521 MPa (76 ksi) for round axisymmetric extrusions to 414 MPa (60ksi) for sheet bar extrusions with an aspect ratio of 8.1 (see Ref. 1). The pole figures for (111), (220), and (200) lattice planes show that the texture is more pronounced with decreasing extrusion aspect ratio, resulting in a very sharp fiber texture for round axisymmetric extrusions.

The pole figures of round extrusions indicate a maximum in the distribution of (111) lattice plane poles in a narrow angular region of about 10° centered around the extrusion axis. With increasing aspect ratio the intensity of (111) poles near the extrusion axis decreased and the angular distribution became wider. The large number of (111) lattice planes oriented nearly perpendicular to the extrusion axis in the case of axisymmetric extrusions might explain in a qualitative way the higher yield strength values observed in tensile tests with the loading axis parallel to the extrusion axis, because of the unfavorable orientation of the (111) slip planes. These results are in accordance with those obtained on an Al-Zn-Mg-Cu (7475) alloy, which also showed that significant texture hardening can be obtained in Al alloys, despite the high symmetry of the FCC lattice (Ref.2).

RELATED PROGRAM ON 2020 ALLOYS

A comparison of microstructure and tensile properties has been made between I/M and P/M 2020 alloys (Al-4.4Cu-1.2Li-0.5Mn). The results obtained for the 2020 alloys will be used in the present program to serve as a comparison to those obtained for the second iteration alloys. The P/M 2020 material was prepared from the I/M alloy by an argon-atomization process. The atomized powder (-200 mesh) was cold compacted, vacuum degassed upon heating to 766K (919°F) and hot compacted. The billets were extruded to round rods with an extrusion ratio of 23:1.

Tensile properties of I/M and P/M 2020 for three different aging conditions are shown in Table 11. It should be noted that these results have been obtained from specimens without intermediate stress relief before aging. Yield stress values were found to be approximately similar for I/M and P/M material, while elongation to fracture values were slightly higher for the I/M specimens. However reduction in area values, which seem to be more suitable for comparison because of specimen necking, are higher for the P/M material. Metallographic studies showed the presence of a significant amount of spherical particles with sizes of up to 70 μm in the P/M material due to impurities introduced during the powder atomization process. SEM examination of fractured P/M 2020 tensile specimens indicated that crack initiation occurred at these large particles. Tests are currently under way on P/M 2020 material with a reduced amount of these detrimental particles due to an improved atomization procedure. It is expected to increase the ductility of the P/M material by removing the large particles.

SECOND ITERATION Al-Li ALLOYS SUPPLIED BY LMSC

Preliminary tensile results have been obtained for two of the second iteration alloys 1.11 (Al-3Cu-2Li) and 1.12 (Al-3Cu-2Li-0.2Zr). The heat treatment procedures previously applied for the first iteration alloys have been adopted for alloys 1.11 and 1.12 to obtain preliminary tensile properties. The solution heat treatment (SHT) was carried out at 811K (1000°F) for 0.5h, followed by cold water quenching and aging at 463K (375°F) for 0.75h, 8h, and 40 h. Some specimen blanks were also stretched 2% after SHT and then aged at 463K for 8 h to study the response with regard to a thermal mechanical treatment. It will be noted that these aging treatments might not have resulted in optimum tensile properties. Age-hardening curves are currently established at LMSC for all four second iteration alloys to select the proper aging treatments for under-, peak-, and over-aged conditions.

The results of the tensile tests are summarized for alloy 1.11 in Table 12 and for alloy 1.12 in Table 13. It can be seen that alloy 1.12 has superior yield strength and ultimate tensile strength values as compared to alloy 1.11.

For example in the peak-aged condition alloy 1.12 showed a yield strength of about 463 MPa (67 ksi) compared to about 391 MPa (57 ksi) obtained for alloy 1.11. A 2% stretch before aging proved to be beneficial with regard to the yield strength as well as the ultimate tensile stress. In the peak-aged condition the yield stress for alloy 1.12 increased from about 463 MPa without stretching to about 544 MPa (79 ksi) with intermediate 2% stretching.

The elongation to fracture values of both second iteration Al-Li alloys are higher as compared to those obtained previously for all of the first iteration Al-Li alloys. Furthermore it should be noted that the intermediate stretching procedure, which resulted in higher yield strength as well as ultimate tensile strength values, did not adversely affect the elongation to fracture values (Tables 12 and 13). Transmission electron microscopy studies of thin foils and scanning electron microscopy investigations of the fracture surface have been initiated to characterize the microstructure and the fracture behavior respectively of these second iteration alloys.

3.4 Task 4 - Application Studies

This task is being performed by Lockheed-California Company under the direction of R. F. Simenz.

The weight savings prediction model has been finalized by the addition of the following two failure mode criteria:

<u>Criterion No.</u>	<u>Failure Criterion</u>	<u>Weight Ratio (W_2 / W_1)</u>
8	General Instability Compression on Shear	$(\rho_2/\rho_1) (E_1/E_2)^{.5}$
9	Minimum Gage	$(\rho_2/\rho_1) (t_2/t_1)$

To prevent confusion in comparing future results with past reported results, it was decided to not combine tensile strength and compression strength into one category (as had been planned). Therefore, the final model has nine failure modes; namely, the original seven plus the two added above. Preliminary calculations indicate that the model change will have only a negligible

effect on the weight savings reported for the Advanced Tactical Fighter and the Vertical/Short Takeoff and Landing airplane.

Material property data generated on the developmental alloys are being reviewed to establish potential design properties for the alloys that come closest to matching the program goals. These design properties will be used in the finalized weight savings prediction model to determine weight savings and the impact of variations from the program goals.

Results of these analyses and recommendations for Phase II alloys, their design properties, processing requirements, and manufacturing limitations will be presented in subsequent reports.

3.5 REFERENCES

1. R. E. Lewis, "Development of Advanced Aluminum Alloys from Rapidly Solidified Powders For Aerospace Structural Applications"; Interim Technical Report for period March '79 - September 1979, AF Contract F33615-78-C-5203, DARPA Order 3417, Lockheed Missiles & Space Company Inc., Report LMSC-D678772, September 1979.
2. K. Welpmann, A. Gysler and G. Lutjering, "Influence of Texture and degree of Recrystallization on the Mechanical Properties of an Al-Zn-Mg-Cu Alloy," to be published in Proc. 7th International Conference on Light Metals, Leoben, Austria, June 1981.

4.0 MAJOR ITEMS OF EXPERIMENTAL OR SPECIAL EQUIPMENT PURCHASED OR CONSTRUCTED DURING THE REPORTING PERIOD

None.

5.0 CHANGE IN KEY PERSONNEL DURING THE REPORTING PERIOD

None.

6.0 NOTEWORTHY TRIPS, MEETINGS, ETC. DURING THE REPORTING PERIOD

None.

7.0 SUMMARY OF PROBLEMS OR AREAS OF CONCERN IN WHICH GOVERNMENT ASSISTANCE OR GUIDANCE IS REQUIRED

None.

8.0 ANTICIPATED DEVIATION IN PLANNED EFFORT TO ACHIEVE CONTRACT OBJECTIVES

The timetable for completion of Phase 1 was changed from September 5, 1980 to December 5, 1980 to accomodate for delays early in the program due to establishment of subcontract arrangements and more recent delays in particulate processing due to safety modifications in ALCOA particulate pilot facilities. The planned start date for Phases 2 and 3 is also changed to correspond to the new completion date for Phase 1.

TABLE 1. OXYGEN CONTENT OF CONSOLIDATED FIRST ITERATION Al-Li-X ALLOYS

Alloy and Extrusion Number	Extrusion Ratio	Consolidation Date	Amount of Particulate Degassing on Vacuum Heating	Loose Flake Oxygen Content *	Consolidated Material	
					Wt %	Oxygen Content Precision ± %
1.1A-2	20:1	3/24/80	High	0.524	0.477	0.007
1.2A-7	20:1	3/05/80	High	0.425	0.417	0.006
1.3A-1	8:1	10/04/79	Very Low	0.705	0.240	0.004
1.4A-1	8:1	10/05/79	High	0.477	0.625	0.009
1.5A-1	8:1	10/09/79	Medium	0.307	0.446	0.006
1.6A-3	20:1	01/11/80	Low	0.516	0.733	0.010
1.7A-3	20:1	02/20/80	Very High	0.467	0.908	0.012
1.8A-1	20:1	01/16/80	Very Low	0.540	0.594	0.008

* Data taken from Table 6, Ref. 1

TABLE 2 PRODUCTION INFORMATION -- ALCOA'S AL-LI ALLOY SPLAT

MATERIALS GENERATION FOR LMSC SECOND ITERATION ALLOYS

LMSC Alloy	Min. Melt Temp. K(°F)	Starting Melt Wt. (kg)	Starting Li Added (kg)	Net Wt. Splat (kg)	Melt Recovery (%)
1.9 Al-2.8Li-1.5Cu-1Mg	1143(1598)	31.82	1.02	6.14	18.7
1.10 Al-2.8Li-1.5Cu-1Mg-0.5Fe-0.5Ni	1143(1598)	31.82	1.02	9.91	30.2
1.11X Al-3Cu-2Li-1Mg*	1143(1598)	31.82	0.91	2.64	8.1
1.11 Al-3Cu-2Li-1Mg	1143(1598)	31.82	0.91	10.68	32.6
1.12 Al-3Cu-2Li-1Mg-0.2Zr	1143(1598)	31.82	0.91	8.0	24.4

*This melt was air atomized.

At beginning of this run an inadvertent loss of argon as the atomizing gas supply occurred. Rather than scrap the melt, splat was produced by air atomization.

TABLE 3. SCREEN FRACTION ANALYSIS RESULTS OF AL-LI SECOND ITERATION

ALLOY SPLAT FLAKES		(Single, Random Sample)									
LMSC Alloy		Screen Size ~ U.S. Standard (% by Weight)									
		+8	+16	-16	+30	-30	+50	-50	+100	-100	+200
1.9	Al-2.8Li-1.5Cu-1Mg	24.5	45.0	19.0	6.5	2.0	1.0	1.0	1.0	1.0	1.0
1.10	Al-2.8Li-1.5Cu-1Mg-0.5Fe-0.5Ni	24.4	39.2	20.4	10.6	4.0	1.0	1.0	0.2	0.2	0.2
1.11X	Al-3Cu-2Li-1Mg*	35.6	35.4	17.2	8.2	2.6	0.6	0.6	0.2	0.2	0.2
1.11	Al-3Cu-2Li-1Mg	8.0	19.0	26.6	25.4	15.0	5.2	0.6	0.6	0.2	0.2
1.12	Al-3Cu-2Li-1Mg-0.2Zr	19.2	38.0	25.0	11.4	4.4	1.6	0.2	0.2	0.2	0.2

*This melt was air-atomized.

TABLE 4. FINAL MELT COMPOSITIONS - AL-LI SECOND ITERATION SPLAT ALLOYS

	<u>LMSC Alloy</u>	<u>Cu</u>	<u>Fe</u>	<u>Si</u>	<u>Mn</u>	<u>Mg</u>	<u>Zn</u>	<u>Cr</u>	<u>Ti</u>	<u>Ni</u>	<u>Zr</u>	<u>Li</u>	<u>Na</u>	<u>Notes</u>
1.9	Al-1.5Cu-2.8Li-1Mg	1.52	.06	.22	.00	.72	.01	.00	.01	.00	.01	2.64	.000	(1)
1.10	Al-1.5Cu-2.8Li-1Mg-0.5Fe-0.5Ni	1.64	.39	.07	.01	.76	.01	.00	.01	.46	.00	2.82	.000	(1)
1.11X	Al-3Cu-2Li-1Mg	3.06	.18	.10	.02	.72	.01	.00	.01	.05	.00	2.18	.000	(2) (3)
1.11	Al-3Cu-2Li-1Mg	2.95	.04	.15	.00	.77	.01	.00	.00	.00	.00	1.54	.000	(1)
1.12	Al-3Cu-2Li-1Mg-0.2Zr	3.00	.04	.04	.00	.79	.01	.00	.00	.01	.16	1.58	.000	(1)

Notes: (1) Average of four (4) samples

(2) Average of two (2) samples

(3) This melt was air atomized

TABLE 5. TENSILE PROPERTIES OF SECOND ITERATION Al-Li ALLOY EXTRUSIONS
SOLUTION TREATED AT 811K (1000°F) AND AGED AT 463K (375°F) FOR 8 h.

Extrusion #	Nominal Composition	Screen Fraction of Particulate	0.2% Yield Strength MPa (ksi)	Ultimate Strength MPa (ksi)	Elongation %
1.9-1	Al-2.8Li-1.5Cu-1Mg	unscreened	244 (35.4)	372 (54.0)	9.9
1.9A-1	"	-8/+50	261 (37.8)	391 (56.7)	12.9
1.10-1	Al-2.8Li-1.5Cu-1Mg-0.5Fe-0.5Ni	unscreened	266 (38.6)	413 (60.0)	7.9
1.10A-1	"	-8/+50	261 (37.9)	410 (59.4)	7.0
1.11-1	Al-3Cu-2Li-1Mg	unscreened	356 (51.6)	446 (64.7)	12.9
1.11A-1	"	-8/+50	354 (51.3)	441 (64.0)	13.7*
1.12-1	Al-3Cu-2Li-1Mg-0.2Zr	unscreened	411 (59.6)	524 (76.0)	12.8
1.12A-1	"	-8/+50	387 (56.1)	510 (73.9)	15.3

* Single specimen result

TABLE 6. THE FIRST ITERATION ALLOY COMPOSITIONS, WT. % (AT %)

<u>Alloy</u>	<u>Si</u>	<u>Mn</u>	<u>Fe</u>	<u>Co</u>	<u>Ni</u>
2.1A	--	--	3.27 (1.67)	3.45 (1.67)	3.44 (1.67)
2.2A	--	--	3.27 (1.67)	4.59 (2.22)	2.28 (1.11)
2.3A	--	--	3.37 (1.67)	2.29 (1.11)	4.57 (2.22)
2.4A	--	--	4.77 (2.50)	5.03 (2.50)	5.00 (2.50)
2.5A	--	9.68 (5.0)	--	--	--
2.6A	2.47 (2.50)	9.68 (5.0)	--	--	--
2.7A	5.06 (5.00)	4.95 (2.50)	--	--	--
2.8A	--	14.2 (7.50)	--	--	--

TABLE 7. THE SIX BETTER ALLOY-PROCESS COMBINATIONS

Alloy	Type	Process ¹	T. S., MPa (ksi)	Y. S., MPa (ksi)	El., %	R. of A., %	$\frac{E/\rho^3}{\text{Mnmkg}^{-1}} (x 10^{-9} \text{ in})$	NTS/YS
2.4A	Splat	2	550 (79.8)	511 (74.2)	3.2	6	29.9 (0.120)	0.56
2.8A	Splat	3	496 (71.9)	460 (66.8)	1.3	1	36.3 (0.146)	0.42
2.2A	Powder	2	426 (61.8)	360 (52.2)	9.2	18	31.3 (0.126)	1.47
2.6A	Powder	3	390 (56.6)	312 (45.3)	14.5	32	28.9 (0.116)	1.61
2.6A	Splat	3	364 (52.8)	305 (44.2)	17.8	45	Note 4	1.74
2.3A	Splat	3	383 (55.6)	306 (44.4)	13.2	31	27.9 (0.112)	1.67

- NOTES: (1) Process 2: Hot press at 675 K (755°F), extrude at 675 K (755°F).
 Process 3: Hot press at 675 K (755°F), extrude at 630 K (675°F).
 (2) Elongation in 5D.
 (3) Goal A = 33.1 MNmkg^{-1} ($.133 \times 10^9 \text{ in}$).
 Goal B = 30.4 MNmkg^{-1} ($.122 \times 10^9 \text{ in}$); $\frac{YS}{\rho} = 198 \text{ kNmkg}^{-1}$ ($.797 \times 10^6 \text{ in}$).
 (4) Not measured.

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TABLE 8. THE FOUR SECOND ITERATION ALLOY COMPOSITIONS, WT. % (AT %)
(NOMINAL COMPOSITIONS)

Alloy	Type	Si	Mn	Fe	Co	Ni	APD ¹ , μm	50% ² , μm
2.9A	Powder	--	12.0 (6.2)	--	--	--	12.0	20.05
2.10A	Powder	2.9 (2.96)	11.6 (6.06)	--	--	--	13.2	20.99
2.11A	Powder	--	--	4.0 (2.06)	4.0 (1.96)	4.0 (1.96)	13.2	23.16
2.12A	Powder	--	--	5.8 (2.99)	--	6.1 (2.99)	13.4	22.58

NOTES: (1) Average particle diameter determined by Fisher subsize sieve analysis.
(2) 50% of powder is smaller than this size, determined by Coulter counter analysis.

TABLE 9. GUINIER PHASE ANALYSIS OF LOOSE POWDER SECOND ITERATION

<u>Alloy</u>	<u>$\alpha\text{-Mn}_3\text{SiAl}_{12}$</u>	<u>$\beta\text{-Mn}_3\text{SiAl}_9$</u>	<u>$(\text{Fe-Ni Co})_2\text{Al}_9$</u>
2.9A	medium	--	--
2.10A	large	v. small+	--
2.11A	--	--	large
2.12A	--	--	large

TABLE 10. PROCESS VARIATIONS FOR THE SECOND ITERATION OF ALLOYS

<u>Process</u>	<u>T_{HOT Press}</u> <u>K (°F)</u>	<u>T_{Extrude}</u> <u>K (°F)</u>	<u>T_{Forge}</u> <u>K (°F)</u>
1	675 (755)	675 (755)	--
2	644 (700)	644 (700)	--
3	644 (700)	--	644 (700)

TABLE 11. TENSILE PROPERTIES OF I/M AND P/M 2020

Alloy	Aging Treatment	$\sigma_{0.2}$ (MPa)	ϵ_f (%)	RA(%)
I/M	15 h 422K	452	8.1	10.1
P/M		462	6.8	13.1
I/M	18 h 433K	542	7.0	8.5
P/M		519	6.4	12.5
I/M	18 h 433K	448	9.8	13.8
P/M	+15 min. 523K	431	7.3	19.3

TABLE 12. TENSILE PROPERTIES OF ALLOY 1.11 (Al-3Cu-2Li)

Aging Condition	$\sigma_{0.2}$ (MPa)	UTS (MPa)	ϵ_f (%)
0.75 h 463K	235	389	15*
	234	386	15*
8 h 463K	390	460	10.6
	393	463	9.9
2% stretch	439	480	10.3
	444	485	10.3
40 h 463K	378	436	9.3
	374	437	8.9

* Specimen elongation exceeded strain gage capacity

TABLE 13. TENSILE PROPERTIES OF ALLOY 1.12 (Al-3Cu-2Li-0.2Zr)

Aging Condition	$\sigma_{0.2}$ (MPa)	UTS (MPa)	ϵ_f (%)
0.75 h 463K	351	503	12.0
	351	503	12.0
8 h 463K	461	531	8.3
	466	537	8.3
2% stretch	541	567	7.4
	546	568	11.4
40 h 463K	436	496	11.0
	438	495	6.4